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Research Article

Designing a Compact High-precision Positioner with Large Stroke Capability for Nanoindentation Devices

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Abstract

A new design of a fine positioner or high precision driven unit with a large positioning range is proposed for a custom-made in-situ indenter device equipped inside an SEM chamber. The design configuration of the proposed system is size-effective for the confined working area of the SEM chamber. The indentation depths can be precisely varied by controlling the fine positioner driven by a piezoelectric actuator. The main goal is to achieve very deep penetrations toward the bottom layers of tall or large-size scale specimens by single indentation, without the need for sequential indentations. Thus, the proposed design can eliminate the need for sequential adjustments of the specimen position with respect to the indenter tip as currently being practiced by the researchers. The specimen position adjustment after each indentation heavily depends on the coarse positioner and its accuracy level in a sub-millimeter regime which could result in position errors and unwanted lateral forces in the nanoindentation process. Therefore, the sequential indentations technique could lead to considerable variations in the outcomes of nanoindentation tests done on similar specimens. The proposed design will be realized to deploy in the Continuous Stiffness Measurement (CSM) techniques generally used to evaluate elastic properties as a function of continuous penetration depth with high-frequency loading and unloading cycles.

INTRODUCTION

A nano-indenter is a tool to provide compression load to a material of interest to determine its mechanical properties such as modulus, hardness, and friction at the micro or nanometer scale [1]. A nano-indenter device can be combined with a Scanning Electron Microscope (SEM) to implement an in situ imaging technique that can enable direct observation of mechanical behaviors of nanoscale materials [2]. Thus, fast and efficient in situ nanoindentation tests can provide new insights into the mechanical behaviors of materials in nanometer regimes. The fine positioners or positioning stages and coarse positioners or positioning stages currently available for in situ nanoindentation devices inside the SEMs are considered large in size and have complex mechanisms. Taking the avails of flexure mechanisms [2], actuator units of positioners provide high-precision motion at the micro or nanometer scale [3]. Small volumes of the SEM chambers demand further development and miniaturization of the in situ nanoindentation devices [4,5]. Besides, some nanoindentation techniques require a large stroke or displacement range of the indenter device, specifically the fine positioner. For example, the Continuous Stiffness Measurement (CSM) technique is used to evaluate elastic properties as a function of continuous penetration depth without the need for discrete unloading cycles [6]. This technique can be very useful to better characterize the beam-like deflection or the foam-like buckling of Vertically Aligned Carbon Nanotube (VACNT) arrays having a height range of 500-1500 μm. However, the maximum stroke or displacement range of the existing high-precision actuators (driven units) is typically 10 μm - 40 μm. The limited stroke is currently addressed by multiple sequential indents to obtain greater depths along the same direction inside the tall VACNT arrays. Despite using this technique, the previous relevant studies [6-8] are limited to the total penetration depths of 100 μm - 200 μm inside the VACNT arrays. This level of penetration depth inside the VACNTs with heights of several hundred μm has been generally achieved by moving the specimen stage 40 μm closer to the indenter tip after each indentation test. This is done by adjusting the position of the Z-axis coarse positioner before the following indentation. Consequently, the accuracy of the specimen stage's sequential position with respect to the indenter tip depends on the accuracy of the Z-axis coarse positioner which usually falls in sub- millimeter regime. Thus, the limitation of this technique is the stage drift during loading after the retraction of the indenter